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FINAL RESULTS OF THE DUVEL BURIED SEED EXPERIMENT[1]

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INTRODUCTION

In 1902 J. W. T. Duvel started a comprehensive experiment at the Arlington Experiment Farm, Rosslyn, Va., to determine the longevity of seeds buried at different depths in the soil under natural conditions. The results after 1 year were reported by Duvel (*6*),[2] and the results involving all tests made during the first 20 years of the experiment were reported by Goss (*7*). Sets of the buried seeds were taken up and tested for viability in the spring of 1932, and again in the fall of 1941, just before the occupation of the Experiment Farm by the United States War Department. The subsequent regrading of the area where the seeds were buried, destroyed the three remaining sets of seeds that it had been intended to test in later years. This report, therefore, completes the record of this experiment on the viability of buried seed.

A number of reports have been published on the germination of seeds of extreme age. J. Ramsbottom, as reported in Nature (*1*), produced seedlings of *Albizzia julibrissin* from seed kept in dry storage for 147 years. Becquerel (*3*) obtained germination of 158-year-old seed of *Cassia multijuga* Rich.

There have been many published reports on the germination of seeds which circumstantial evidence indicated had been in the soil many years, but it is believed that the first experiment definitely planned to determine the longevity of seeds experimentally buried in the soil was that started by Beal (*2*) in Michigan in 1879. Darlington (*4*), in reporting on Beal's experiment after 60 years, found the seeds of 2 and possibly 4 of the 20 buried species surviving. Since the publication by Goss (*7*) on Duvel's experiment, several publications have appeared on other studies of the longevity of seeds buried in the soil, completed or in progress. Dorph-Petersen (*5*) mentioned the germination after 18 years of seeds of *Plantago lanceolata* L. buried in soil at the Danish State Seed Testing Station in 1899. He also reported the viability after 6 years of 7 out of 13 species buried at 3 depths in 1904. Goss (*8*) buried 12 species of weed seeds in California in both irrigated and nonirrigated soil; after 6 years, 5 species were viable from the irrigated and 6 from the nonirrigated soil.

[1] Received for publication August 3, 1944.

[2] Italic numbers in parentheses refer to Literature Cited, p. 209.

Goss and Brown (*9*) found that, of the seeds of cultivated and weed rices buried in irrigated and nonirrigated soil in Arkansas, Texas, and California and tested at intervals for 7 years, the weed rices survived longer than the cultivated and longer when the soil was flooded than when it was not. Kjaer (*10*) found that 20 out of 37 samples of crop and weed seeds germinated better at the end of 5 years when buried in the soil than when held in dry storage. Muenscher (*11, p. 6*) reported viable seeds at the end of 5 years of all but 3 of 21 kinds of weed seeds buried in clay and in sandy soil at Ithaca, N. Y., in 1928.

MATERIALS AND METHODS

Detailed descriptions of the methods of burial of the seed and of the germination of the seed after removal from the soil have been given by Duvel (*6*) and by Goss (*7*). Seeds of 107 species of crop plants and weeds harvested in 1902 (except 2 samples of red clover of the 1900 harvest) were used. Counted seeds of each species, mixed with sterilized soil, were placed in flowerpots, which were then covered with inverted porous flowerpot saucers. An excavation was made with level soil surfaces at 8, 22, and 42 inches below the ground level. Twelve sets of flowerpots containing soil and seeds were placed at each of the deeper levels, and 8 sets were placed at the shallower level. Soil was then carefully packed around the pots, and the excavation was filled to the normal ground level. For the larger seeds, such as

FIGURE 1.—Set of buried seeds at the 42-inch depth, uncovered for removal and germination test in May 1932.

corn, wheat, beans, and cotton, 100 seeds were placed in each pot, but for most kinds 200 seeds were used. The pots ranged in diameter from 2 to 6 inches, depending on the size of the seeds. Sets were removed and tested in 1903, 1905, 1908 (two sets as reported by Goss (7), 1912, 1918, 1923, 1932, and 1941. The appearance of the covered pots at the 42-inch depth, when uncovered and ready for removal in 1932, is shown in figure 1.

In 1932, seeds from the three depths were removed from the soil on May 4 and promptly tested for germination. The set removed October 11, 1941, represented only the 22- and 42-inch depths, as all the sets at 8 inches had been removed previously. The seeds were tested for viability in sterilized soil in a greenhouse, essentially as described by Goss (7). No tests were discarded until the soil had been examined carefully for sound seeds. Where sound seeds were recovered, they were scarified if they had failed to absorb water or were stratified at a low temperature if they appeared otherwise dormant. It is believed that failure to germinate was not due to lack of suitable germination conditions. When the soil and seeds were being removed from the pots, it was found that ants and earthworms had been active in the soil in some pots, so that some seeds may have been moved or destroyed.

EXPERIMENTAL DATA

The seeds of 15 species of crop plants and 3 species of weeds did not survive even 1 year in the soil. The seeds that never germinated were barley (*Hordeum vulgare* L. [*H. sativum* Jessen]); bean (*Phaseolus vulgaris* L.); buckwheat (*Fagopyrum esculentum* Moench [*F. fagopyrum* (L.) Karst.]); cotton (*Gossypium hirsutum* L.); flax (*Linum usitatissimum* L.); hemp (*Cannabis sativa* L.); maize (*Zea mays* L.), both field and sweet; muskmelon (*Cucumis melo* L.); oats (*Avena sativa* L.); onion (*Allium cepa* L.); pea (*Pisum sativum* L.); rye (*Secale cereale* L.); sunflower, cultivated, (*Helianthus annuus* L.); watermelon (*Citrullus vulgaris* Schrad. [*C. citrullus* (L.) Karst.]); wheat (*Triticum aestivum* L.); chess (*Bromus secalinus* L.); corncockle (*Agrostemma githago* L.); and Russian pigweed (*Axyris amaranthoides* L.). In addition, 8 species germinated so little as to be considered negligible. These were asparagus (*Asparagus officinalis* L.); cabbage (*Brassica oleracea* L.); cowpea (*Vigna cylindrica* (Stickm.) Skeels [*V. catjang* Walp.]); lettuce (*Lactuca sativa* L.); meadow fescue (*Festuca elatior* L.); pepper (*Capsicum frutescens* L. [*C. annum* L.]); scrub pine (*Pinus virginiana* Mill.); and tomato (*Lycopersicon esculentum* Mill. [*L. lycopersicum* L.]). None of these germinated more than 1 percent or more than 1 year with the exception of tomato and lettuce, which germinated 2 different years. Table 1 gives the germination percentages obtained each time the seeds were tested for all kinds except those just listed. To facilitate reference to the previous publications on the experiment, the scientific names used in the original publication by Duvel (6) are given in brackets when they differ from the names now regarded as valid. Half percents have been raised to the next higher percent.

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TABLE 1.—*Germination in different years of various kinds of seeds buried in 1902*

[All kinds of seeds buried except those listed on page 203 as germinating little or none are included; names used by Duvel (*6*) that differ from present usage appear in brackets]

Family and plant	Depth buried	Seeds germinated in—							
		1903	1905	1908	1912	1918	1923	1932	1941
Poaceae:	*Inches*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*
Agropyron repens (L.) Beauv. (couch grass)	8	21	0	0	0	0	0	0	
	22	73	1	0	0	0	0	0	0
	42	67	19	1	2	0	0	0	0
Avena fatua L. (wild oats)	8	9	0	0	0	0	0	0	
	22	8	0	0	0	0	0	0	0
	42	18	0	0	0	0	0	0	0
Bromus racemosus L. (upright chess)	8	0	0	12	0	0	0	0	
	22	0	0	43	0	0	0	0	0
	42	0	0	19	0	0	0	0	0
Eleusine indica (L.) Gaertn. (goosegrass)	8	0	3	1	0	0	0	0	
	22	0	3	1	0	0	0	0	0
	42	0	3	1	0	0	0	0	0
Elymus canadensis L. (nodding wild-rye)	8	0	1	0	0	0	0	0	
	22	7	1	0	0	0	0	0	0
	42	22	0	0	0	0	0	0	0
Elymus triticoides Buckl. (wild wheat)	8	2	0	0	0	0	0	0	
	22	4	0	0	0	0	0	0	0
	42	16	0	0	0	0	0	0	0
Elymus virginicus L. (Virginia wild-rye)	8	2	0	0	0	0	0	0	
	22	14	0	0	0	0	0	0	0
	42	26	0	0	0	0	0	0	0
Panicum virgatum L. (switchgrass)	8	4	7	0	0	0	0	0	
	22	9	15	0	0	0	0	0	0
	42	8	15	0	0	0	0	0	0
Phalaris arundinacea L. (reed canary grass)	8	45	40	30	13	12	5	0	
	22	47	62	53	47	7	12	1	0
	42	57	63	38	16	0	1	0	0
Phleum pratense L. (timothy)	8	0	0	35	23	3	1	0	
	22	0	0	56	22	2	5	0	0
	42	0	0	47	51	6	13	0	0
Poa pratensis L. (Kentucky bluegrass)	8	16	42	0	17	17	13	1	
	22	22	66	21	5	27	11	3	1
	42	25	81	47	4	0	19	12	2
Setaria lutescens (Weigel) F. T. Hubb. [*Chaetochloa glauca* (L.) Scribn.] (yellow foxtail)	8	1	3	6	4	0	0	1	
	22	1	2	2	5	2	0	0	0
	42	1	2	2	1	0	1	0	0
Setaria verticillata (L.) Beauv. [*Chaetochloa verticillata* (L.) Scribn.] (foxtail)	8	29	49	40	30	8	7	2	
	22	36	48	38	35	3	3	0	1
	42	45	62	43	48	1	2	0	1
Setaria viridis (L.) Beauv. [*Chaetochloa viridis* (L.) Scribn.] (green foxtail)	8	0	56	16	39	29	2	0	
	22	0	59	13	26	5	6	1	1
	42	0	68	27	80	2	26	0	0
Sporobolus airoides Torr. (hairgrass dropseed)	8	0	0	0	0	0	0	0	
	22	0	0	7	0	0	5	0	0
	42	0	0	0	8	0	1	0	0
Sporobolus cryptandrus (Torr.) A. Gray (sand dropseed)	8	1	0	1	0	0	0	0	
	22	2	0	7	0	0	4	0	1
	42	14	0	0	0	0	59	5	0
Sporobolus cryptandrus (Torr.) A. Gray (sand dropseed), hulled seed	8	0	0	0	5	0	0	0	
	22	0	0	0	8	0	21	5	2
	42	0	0	0	0	0	75	1	0
Cyperaceae:									
Cyperus esculentus L. (yellow nutgrass)	8	0	2	5	7	1	9	0	
	22	0	3	6	21	5	5	0	0
	42	0	2	0	14	0	17	0	0
Urticaceae:									
Boehmeria nivea (L.) Gaud. (ramie)	8	0	6	0	7	11	39	14	
	22	0	44	0	10	32	61	14	3
	42	0	51	0	26	32	71	20	6
Polygonaceae:									
Polygonum pensylvanicum L. (smartweed)	8	0	0	0	1	4	0	2	
	22	0	0	0	3	0	0	1	0
	42	0	0	1	1	0	0	8	0
Polygonum persicaria L. (ladysthumb)	8	0	26	0	61	14	1	3	
	22	0	1	0	32	9	26	9	0
	42	0	0	0	8	1	55	9	0
Polygonum scandens L. (climbing false buckwheat)	8	0	0	0	0	1	0	0	
	22	0	0	0	0	0	3	0	0
	42	0	0	0	0	0	5	0	1
Rumex crispus L. (curled dock), not cleaned	8	68	69	64	61	43	9	0	
	22	80	65	67	76	0	24	1	1
	42	79	58	51	73	19	14	12	6

TABLE 1.—*Germination in different years of various kinds of seeds buried in 1902*—Continued

Family and plant	Depth buried	Seeds germinated in—							
		1903	1905	1908	1912	1918	1923	1932	1941
Polygonaceae—Continued.	*Inches*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*
Rumex obtusifolius L. (broad-leaved dock)	8	73	92	89	83	57	59	21	.....
	22	73	92	84	86	90	78	33	3
	42	80	94	87	89	84	83	19	5
Rumex salicifolius Weinm. (willow-leaved dock)	8	89	67	33	83	58	0	6	.....
	22	86	76	19	62	84	73	46	2
	42	71	68	23	94	89	55	24	6
Chenopodiaceae:									
Beta vulgaris L. (sugar beet)	8	14	0	8	1	0	0	0	.....
	22	59	10	35	1	0	1	0	0
	42	40	7	9	4	2	1	0	0
Chenopodium album L. (lambsquarters)	8	32	37	1	39	30	0	0	.....
	22	64	41	50	37	47	0	24	7
	42	65	51	1	62	47	66	17	9
Chenopodium hybridum L. (maple-leaved goosefoot)	8	8	14	1	37	0	0	0	.....
	22	10	30	9	27	15	41	9	0
	42	13	34	42	40	11	0	0	2
Amaranthaceae:									
Amaranthus retroflexus L. (rough pigweed)	8	9	0	1	11	0	0	0	.....
	22	11	20	68	36	0	0	0	0
	42	18	12	10	48	0	0	0	0
Phytolaccaceae:									
Phytolacca americana L. (pokeweed)	8	8	66	29	88	0	[1] 0	82	.....
	22	67	91	69	93	88	75	62	81
	42	81	94	77	77	93	73	76	90
Portulacaceae:									
Portulaca oleracea L. (purslane)	8	39	15	37	22	13	9	1	.....
	22	39	31	34	27	20	0	0	0
	42	31	39	11	7	15	38	0	0
Caryophyllaceae [Silenaceae]:									
Saponaria vaccaria L. [*Vaccaria vaccaria* (L.) Britton] (cowherb)	8	0	0	0	0	0	0	0	.....
	22	4	0	1	0	0	0	0	0
	42	7	0	1	28	0	0	0	0
Stellaria media (L.) Cyr. [*Alsine media* L.] (chickweed)	8	91	65	3	6	0	0	0	.....
	22	97	81	47	3	0	0	0	0
	42	93	70	50	22	0	0	0	0
Brassicaceae:									
Brassica nigra (L.) Koch (black mustard)	8	5	27	0	2	0	0	0	.....
	22	7	11	1	25	0	38	0	0
	42	7	9	0	26	0	1	0	0
Brassica rapa L. [*B. campestris* L.] (turnip)	8	0	0	0	0	0	0	0	.....
	22	0	0	1	0	0	0	0	0
	42	1	2	1	3	0	0	0	0
Capsella bursa-pastoris (L.) Medik. [*Bursa bursa-pastoris* (L.) Britton] (shepherds-purse)	8	0	6	0	2	0	0	0	.....
	22	0	31	5	6	----	0	0	0
	42	0	28	20	17	47	0	0	0
Erysimum cheiranthoides L. (wormseed)	8	1	0	1	0	0	0	0	.....
	22	3	1	0	0	0	0	0	0
	42	4	0	1	0	0	0	0	0
Neslia paniculata (L.) Desv. (ballmustard)	8	23	3	0	10	0	0	0	.....
	22	25	6	0	8	0	0	0	0
	42	39	11	3	14	0	0	0	0
Sisymbrium altissimum L. (tall sisymbrium)	8	11	22	79	0	0	0	0	.....
	22	18	17	7	3	0	0	0	0
	42	26	49	0	17	0	0	0	0
Thlaspi arvense L. (field pennycress)	8	11	10	34	0	0	0	0	.....
	22	8	62	52	46	0	1	11	0
	42	12	31	8	10	0	0	1	0
Rosaceae:									
Potentilla norvegica L. [*P. monspeliensis* L.] (rough cinquefoil)	8	10	90	64	21	47	83	3	.....
	22	16	92	63	97	----	69	10	22
	42	22	95	55	89	59	91	7	33
Caesalpiniaceae:									
Cassia marilandica L. (wild senna)	8	3	9	14	14	3	1	2	.....
	22	3	23	14	7	5	0	0	0
	42	5	25	15	14	3	2	0	0
Fabaceae:									
Lespedeza intermedia (S. Wats.) Britton *L. frutescens* (L.) Britton] (bushclover)	8	0	1	0	5	0	[2] 16	[3] 1	.....
	22	0	1	1	3	0	[2] 34	[3] 2	[2] 18
	42	1	2	2	3	0	[2] 48	[3] 1	[2] 32
Medicago sativa L. (alfalfa)	8	2	4	1	0	0	0	0	.....
	22	9	1	1	0	0	0	0	0
	42	9	1	0	0	0	0	0	0

See footnotes at end of table.

TABLE 1.—*Germination in different years of various kinds of seeds buried in 1902*—Continued

Family and plant	Depth buried	Seeds germinated in—							
		1903	1905	1908	1912	1918	1923	1932	1941
Fabaceae—Continued.	*Inches*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*
Robinia pseudoacacia L. (black locust)	8	0	5	5	22	20	[2] 27	[2] 34	
	22	0	1	5	13	6	[2] 28	[2] 33	[2] 30
	42	0	3	4	18	3	[2] 31	[2] 36	[2] 4
Trifolium hybridum L. (alsike clover)	8	2	2	0	3	3	2	0	
	22	4	3	1	2	1	5	2	0
	42	5	2	2	6	4	6	2	0
Trifolium pratense L. (red clover)	8	1	0	0	1	1	3	[4] 1	
	22	2	0	0	1	1	4	[4] 2	[2] 2
	42	2	0	0	3	0	2	[4] 0	[2] 2
Trifolium pratense L. (red clover), 1900 harvest	8	5	2	1	4	4	[4] 6	[4] 0	
	22	5	2	2	10		[4] 6	[4] 2	[2] 3
	42	6	6	2	33	1	[4] 2	[4] 3	[2] 3
Trifolium pratense L. (red clover), hard seed from above sample (1900)	8	11	4	4	1	15	[4] 16	[4] 1	
	22	16	3	7	2		[4] 16	[4] 5	[2] 16
	42	15	5	6	4	1	[4] 9	[4] 8	[2] 12
Trifolium repens L. (white clover)	8	0	0	0	3	3	[4] 0	1	
	22	1	0	0	5	0	[4] 1	2	0
	42	0	0	1	3	2	[4] 0	0	0
Anacardiaceae:									
Rhus glabra L. (smooth sumac)	8	0	0	0	1	0	0	2	
	22	0	0	0	0	0	0	1	2
	42	2	0	0	0	0	0	0	0
Malvaceae:									
Abutilon theophrasti Medik. [*A. abutilon* L.] (velvetleaf)	8	0	0	45	70	75	[2] 70	[5] 13	
	22	0	0	25	77	78	[2] 62	[5] 12	[2] 38
	42	0	0	30	72	76	[2] 58	[5] 6	[2] 48
Hibiscus militaris Cav. (halberd-leaved rosemallow)	8	0	0	38	74	70	58	25	
	22	0	0	67	81	58	36	42	[2] 8
	42	0	0	47	74	63	47	47	[2] 9
Hypericaceae:									
Ascyrum hypericoides L. (St.-Andrew's-cross)	8	1	0	0	0	0	0	8	
	22	0	0	0	0	0	0	16	0
	42	1	0	0	0	0	0	13	5
Onagraceae:									
Oenothera biennis L. [*Onagra biennis* (L.) Scop.] (evening-primrose)	8	0	48	0	74	58	61	32	
	22	0	67	0	86	57	88	6	17
	42	0	71	0	90	45	87	59	18
Apiaceae:									
Apium graveolens L. (celery)	8	49	19	1	23	2	0	0	
	22	64	23	4	15	2	11	2	0
	42	60	38	21	32	9	11	1	1
Pastinaca sativa L. (wild parsnip)	8	15	6	15	3	0	0	0	
	22	26	7	11	3	0	0	0	0
	42	32	11	36	14	3	0	0	0
Oleaceae:									
Fraxinus americana L. (white ash)	8	0	0	4	0	0	0	0	
	22	0	0	12	0	0	0	0	0
	42	84	0	4	0	0	0	0	0
Convolvulaceae:									
Convolvulus sepium L. (hedge bindweed)	8	2	29	11	41	47	27	20	
	22	4	11	14	51	66	41	43	34
	42	7	13	21	43	64	43	51	53
Cuscuta epilinum Weihe (flax dodder)	8	16	0	0	0	0	0	0	
	22	24	0	0	0	0	0	0	0
	42	34	0	0	9	0	0	0	0
Cuscuta polygonorum Engelm. (smartweed dodder)	8	12	10	2	16	(6)	(6)	12	
	22	11	16	4	15	(6)	(6)	12	0
	42	13	16	3	10	(6)	(6)	13	1
Ipomoea lacunosa L. (small-flowered white morning-glory)	8	20	80	68	22	6	7	3	
	22	25	94	72	57	71	52	49	31
	42	33	88	92	83	2	57	39	21
Verbenaceae:									
Verbena hastata L. (blue vervain)	8	12	13	0	41	0	83	1	
	22	13	20	0	45	0	71	4	1
	42	14	24	0	26	0	0	2	0
Verbena urticifolia L. (white vervain)	8	24	1	0	19	58	83	1	
	22	25	4	1	24	0	90	46	5
	42	27	0	0	21	64	78	0	1
Solanaceae:									
Datura stramonium L. [*D. tatula* L.] (jimsonweed)	8	86	41	76	78	24	55	81	
	22	84	38	99	95	82	78	88	91
	42	87	40	91	95	98	56	8	88
Nicotiana tabacum L. (tobacco)	8	47	1	28	40	19	46	13	
	22	70	5	45	50	26	36	8	22
	42	55	19	44	79	29	56	22	17

See footnotes at end of table.

TABLE 1.—*Germination in different years of various kinds of seeds buried in 1902*—Continued

Family and plant	Depth buried	Seeds germinated in—							
		1903	1905	1908	1912	1918	1923	1932	1941
Solanaceae—Continued.	*Inches*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*
Solanum nigrum L. (black nightshade)	8	10	77	31	3	0	82	82	------
	22	11	67	52	81	20	74	42	83
	42	13	63	27	90	29	95	63	79
Scrophulariaceae:									
Verbascum thapsus L. (common mullein)	8	7	18	11	63	38	86	21	------
	22	8	26	8	41	72	90	15	48
	42	26	29	3	83	32	93	57	35
Plantaginaceae:									
Plantago lanceolata L. (buckhorn)	8	21	34	19	4	0	0	0	------
	22	21	51	14	3	0	0	0	0
	42	21	62	17	4	2	0	0	0
Plantago major L. (common plantain)	8	40	68	11	53	18	6	0	------
	22	44	60	10	32	31	14	1	0
	42	47	55	15	41	20	84	0	0
Plantago rugelii Decne. (Rugel's plantain)	8	12	68	4	84	33	0	0	------
	22	12	56	6	75	30	21	0	0
	42	14	66	6	16	24	37	0	0
Cucurbitaceae:									
Cucumis sativus L. (cucumber)	8	0	0	0	0	0	0	0	------
	22	1	0	0	0	0	0	0	0
	42	3	0	0	0	0	0	0	0
Cichoriaceae:									
Lactuca serriola L. [*L. scariola* L.] (prickly lettuce)	8	64	75	0	0	0	0	0	------
	22	69	59	0	0	0	0	0	0
	42	70	67	0	0	0	0	0	0
Taraxacum laevigatum (Willd.) DC. [*T. erythrospermum* Andrz.] (red-seeded dandelion)	8	36	29	7	0	0	0	0	------
	22	42	5	1	0	0	0	0	0
	42	46	2	8	0	0	0	0	0
Ambrosiaceae:									
Ambrosia artemisiifolia L. (ragweed)	8	16	13	12	66	69	2	21	------
	22	19	12	6	69	69	84	57	6
	42	21	16	4	62	81	79	10	22
Ambrosia trifida L. (great ragweed)	8	0	0	0	5	0	1	0	------
	22	2	9	0	13	12	15	0	0
	42	6	8	0	6	2	6	0	0
Xanthium pensylvanicum Wallr. (cocklebur) [7]	8	0	0	0	5	15	0	0	------
	22	0	0	45	5	15	0	0	0
	42	5	0	25	(8)	0	0	0	0
Asteraceae:									
Arctium lappa L. (burdock)	8	43	32	12	53	11	0	0	------
	22	64	58	17	74	34	29	0	0
	42	73	54	26	93	67	17	0	1
Bidens frondosa L. (beggarticks)	8	15	0	53	40	1	0	0	------
	22	17	0	38	64	0	0	0	0
	42	18	0	61	65	0	0	0	0
Chrysanthemum leucanthemum L. (oxeye daisy)	8	21	79	47	78	38	43	4	------
	22	33	79	62	57	37	48	2	1
	42	50	76	82	82	20	39	5	0
Cirsium arvense (L.) Scop. [*Carduus arvensis* L.] (Canada thistle)	8	21	35	15	6	3	1	0	------
	22	23	29	16	10	1	1	0	0
	42	29	39	26	21	3	5	0	0
Grindelia squarrosa (Pursh) Dunal (gumplant)	8	31	22	7	4	0	0	0	------
	22	36	11	2	0	0	0	0	0
	42	42	11	5	14	0	0	0	0
Helianthus annuus L. (wild sunflower)	8	44	0	0	0	0	0	0	------
	22	64	0	0	0	0	0	0	0
	42	67	0	0	0	0	0	0	0
Onopordum acanthium L. (Scotch thistle)	8	86	0	82	40	37	37	6	------
	22	93	0	91	72	42	4	53	46
	42	91	0	87	62	32	8	62	30
Rudbeckia hirta L. (black-eyed-susan)	8	7	36	2	53	20	31	12	------
	22	7	41	2	58	49	57	37	0
	42	7	59	3	66	10	52	30	33

[1] 17 percent sound seeds were recovered.
[2] Includes some hard seeds which were recovered and germinated after scarification.
[3] Hard seeds were not recovered.
[4] In addition, some hard seeds which germinated after scarification were recovered.
[5] In addition, 236 hard seeds were recovered from the 3 depths combined. All germinated after scarification.
[6] Estimated, about 25 percent.
[7] Only 10 fruits with 2 seeds each were buried at each depth.
[8] Record of 25 sprouts evidently an error, perhaps due to root sprouts.

Most viable seeds of the hard-seeded legumes did not germinate until the seed coats were scarified to allow absorption of water, after which germination followed quickly. When dug up in the fall of 1941, the seeds of ragweed (*Ambrosia*) did not germinate under greenhouse conditions but, after the seeds in soil had been kept at 50° F. for about 2 months, germination was prompt.

The seeds of St.-Andrew's-cross (*Ascyrum hypericoides*) showed almost no germination until the test of 1932, when an average of 12 percent of seedlings was obtained from the three depths. In that test the flats were kept for a long period; the first germination of this species occurred approximately 6 months after the seeds were dug up. This delayed germination is in extreme contrast to the behavior of morning-glory (*Ipomoea lacunosa*), seedlings of which appeared within 72 hours after removal from burial in 1932.

For many species there was a gradual or marked decrease of germination in the successive tests; but others, notably pokeweed (*Phytolacca*), jimsonweed (*Datura*), and black nightshade (*Solanum*), maintained a remarkably high germination percentage even after 39 years in the soil.

DISCUSSION

It is worthy of note that the seeds of crop plants having large seeds did not persist even 1 year. The contrast within a species is shown by the sunflower (*Helianthus*); the seed of the cultivated strain did not survive 1 year, whereas 44 to 67 percent of the seeds of the wild sunflower germinated after 1 year although they did not grow thereafter. Even after 39 years there was some viability of some crop plants, including tobacco (*Nicotiana*), red clover (*Trifolium*), celery (*Apium*), and Kentucky bluegrass (*Poa*).

It is probable that the ability of seeds to persist in the soil is connected with the physiological condition known as dormancy. The type of dormancy involved would seem to vary in different species. The seeds of morning-glory (*Ipomoea*) would appear to have been inhibited from germinating by a reduced oxygen supply, as they germinated immediately when brought to the surface, whereas after 39 years in the soil the seeds of ragweed (*Ambrosia*) and St.-Andrew's-cross (*Ascyrum*) required a long period of preparation or special treatment before germination started.

Although the seeds reported as retaining viability in dry storage for long periods have been in general of the hard-seeded type, many of the species reported here as germinating after 39 years in the soil are not hard-seeded but have absorbed moisture while in the soil. While the duration of this buried seed test did not equal the length of time that certain dry seeds have retained their viability, the high germination percentage of seeds of jimsonweed (*Datura*), pokeweed (*Phytolacca*), and black nightshade (*Solanum*), after being buried in the soil for 39 years, indicates the possibility that these species might persist in the soil even longer than the records for seeds in dry storage.

Marked irregularities are apparent in the percentages of germination of the same species from different depths and for succeeding years. These differences may be due both to local differences in environment indirectly brought about by the activity of ants and earthworms already noted and to actual disturbance of the seeds by these organ-

isms. The record of survival of some seeds of a species may be of more significance than the germination percentage. Even though the germination percentages from different levels were often very irregular, the general tendency has been for the seeds from the depth of 8 inches to germinate less than those from the depth of 42 inches. Of the total number of seedlings obtained from 1903 through 1932, approximately 27 percent were from the 8-inch, 34 percent from the 22-inch, and 39 percent from the 42-inch level. This proportion did not vary greatly for the different years.

SUMMARY

In tests to determine the viability of buried seeds it was found that of 107 species buried in 1902, 71 grew after 1 year, 61 grew after 3 years, 68 grew after 6 years, 68 grew after 10 years, 51 grew after 16 years, 51 grew after 20 years, 44 grew after 30 years, and 36 grew after 39 years.

The following 10 species that grew in 1923 failed to grow in 1932: *Ambrosia trifida*, *Arctium lappa*, *Beta vulgaris*, *Brassica nigra*, *Cirsium arvense*, *Cyperus esculentus*, *Phleum pratense*, *Plantago rugelii*, *Polygonum scandens*, and *Sporobolus airoides*. Of these, *A. lappa* and *P. scandens* showed some life again in 1941, and 3 species that grew in 1932 (*Ascyrum hypericoides*, *Polygonum pensylvanicum*, and *Rhus glabra*) had failed to germinate in 1923.

The following 10 species that grew in 1932 failed to germinate in 1941: *Cassia marilandica*, *Phalaris arundinacea*, *Plantago major*, *Polygonum pensylvanicum*, *P. persicaria*, *Portulaca oleracea*, *Setaria lutescens*, *Thlaspi arvense*, *Trifolium hybridum*, and *T. repens*.

The 16 species, representing 10 plant families, having the highest percentage of germination in 1941 (more than 15 percent from at least one depth) were *Abutilon theophrasti*, *Ambrosia artemisiifolia*, *Convolvulus sepium*, *Datura stramonium*, *Ipomoea lacunosa*, *Lespedeza intermedia*, *Nicotiana tabacum*, *Oenothera biennis*, *Onopordum acanthium*, *Phytolacca americana*, *Potentilla norvegica*, *Robinia pseudoacacia*, *Rudbeckia hirta*, *Solanum nigrum*, *Trifolium pratense*, and *Verbascum thapsus*. Of the 20 other species that showed some life after 39 years, 18 species had not more than 6 percent of germination at either depth.

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CHECKING OF FRUITS OF THE DEGLET NOOR DATE IN RELATION TO WATER DEFICIT IN THE PALM[1]

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INTRODUCTION

Minute cracks in the surface of fruits of the date (*Phoenix dactylifera* L.) may appear during the summer after a period of rain or

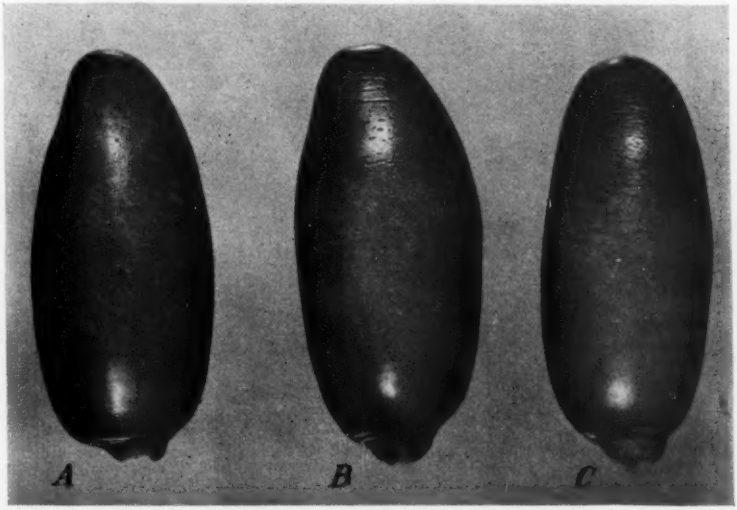

FIGURE 1.—Checking on fruits of the Deglet Noor date on August 10, 1942. *A*, No visible checking; *B*, moderate amount of checking; *C*, severe checking, typical of that which develops into blacknose. The checks on fruit *C* and on the left edge of fruit *B* are 4 to 5 days old; the checks in the middle of fruit *B* are only a few hours old.

high relative humidity (fig. 1, *B*). Such cracking, known by California date growers as checking, has been observed on fruits of most varieties. On the Deglet Noor variety such checking, if severe

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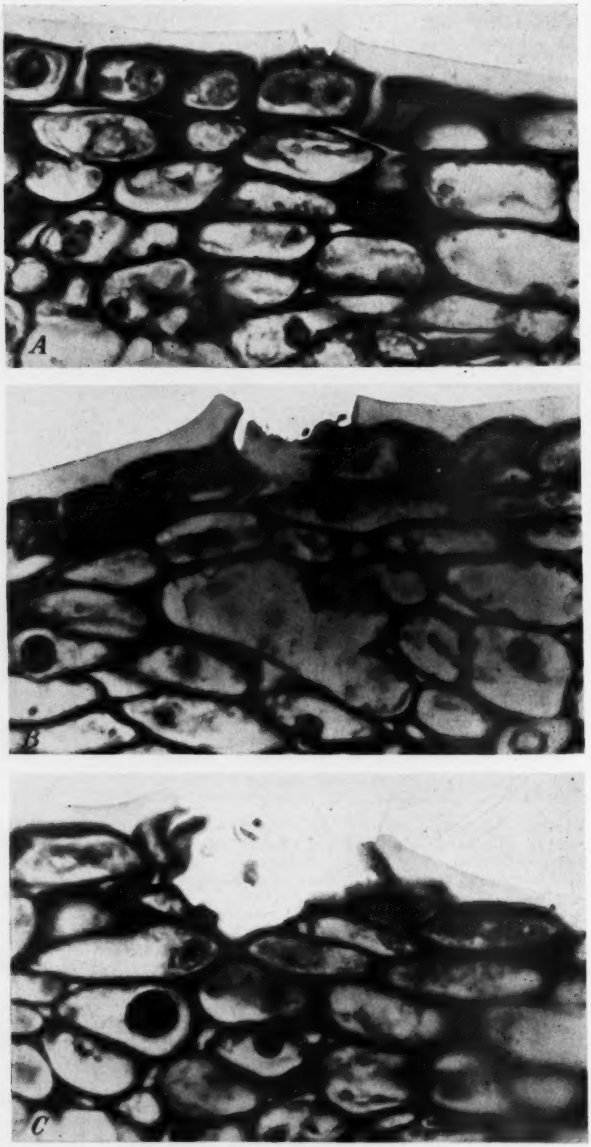

FIGURE 2.—*A–C*, Radial longisections through epidermal and hypodermal cells of Deglet Noor fruits approximately 10 hours after minute cracks appeared. Note in *A* the minute crack in the cutinous layer, extending into an epidermal cell; in *B* the ruptured epidermal cell, with the extended hypodermal cells just below; and in *C* ruptured cells in hypodermal as well as in epidermal layer. (Photomicrographs by E. M. Long.)

(fig. 1, *C*), may eventually cause a darkening and shriveling called blacknose. The minute cracks constituting the checking start in the epidermal cells and involve initially only two or three layers of hypodermal cells (fig. 2). Severe checking and blacknose of Deglet Noor appreciably reduce the total production of marketable fruit in the Coachella Valley of California in about 1 out of every 5 years, and in some locations they lower the commercial grade of part of the crop almost every year.

Susceptibility of Deglet Noor fruits to checking ceases when the fruits reach full size and the color changes from yellowish green to pink. Thereafter, while the fruits are pink (the khalal stage), rain injury is manifested either by a splitting, called tearing, or by many long but narrow cracks, which will be referred to as khalal cracking.

Pathological studies reported by Klotz (*6*) [3] and Fawcett and Klotz (*3*) indicated that no micro-organism was responsible for blacknose, but that showers or periods of high humidity might be involved. An increase in checking or blacknose after late-spring or early-summer bagging of branches was observed by Nixon (*9*). Klotz (*6*) was able to produce khalal cracking by placing strands of fruits in chambers at 100, 89.9, and 80.5 percent humidity. In a comprehensive study of checking, Haas and Bliss (*5*) found that covering fruit bunches with paper tubes during the period of fruit susceptibility to checking increased this injury and separating the strands to facilitate air circulation reduced it. Later Nixon and Crawford (*10*) showed that reducing the number of fruits per bunch, either by removing flowers at time of pollination in March or by removing fruits on June 1 increased both checking and blacknose.

To obtain a better understanding of the action of water in the development of checking on Deglet Noor fruits, studies were conducted at the United States Date Garden, Indio, Calif., from 1938 to 1941, to ascertain: (1) Period of fruit susceptibility to checking as determined by immersion of detached fruits in water; (2) relation of checking to water intake by detached fruits immersed in water and in sucrose solutions; (3) effect upon checking of varying the water supplied to detached strands of fruits; (4) effect upon checking of various water-vapor-pressure deficits of air surrounding fruits on the palm; (5) rate of transpiration of fruits on the palm; and (6) the degree of checking of fruits on the palm in relation to appreciable water deficits in the palm. The results of the studies are reported herein.

RESULTS

PERIOD OF FRUIT SUSCEPTIBILITY TO CHECKING

Since both Nixon (*9*) and Haas and Bliss (*5*) were able to cause Deglet Noor fruits to check by immersing them in water for 24 to 48 hours, a modification of this technique was used to determine the period of fruit susceptibility. During the summer fruits were removed weekly from the bunch between 6:30 and 7:30 a. m., and within an hour they were immersed in water at 26° to 30° C. The severed vascular tissues were not sealed. At the end of 4 hours the fruits were removed and wiped dry, and their surfaces were examined for minute cracks.

[3] Italic numbers in parentheses refer to Literature Cited, p. 231.

Preliminary work in 1938 showed that the fruits were susceptible to checking throughout July and during part of August and that susceptibility decreased at about the time the fruit reached maximum size and the color changed from yellowish green to pink. These results are in agreement with those of Nixon (*9*) and of Haas and

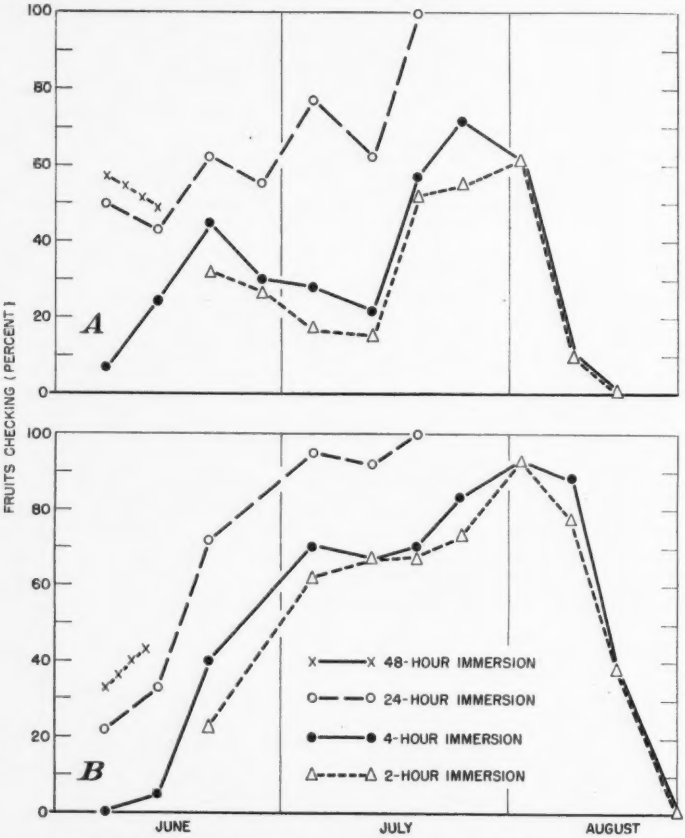

FIGURE 3.—Date fruits checking after different periods of immersion, in weekly samples, 1939: *A*, From United States Date Garden; *B*, from Cavanagh garden.

Bliss (*5*). To determine the time or stage of fruit development at which susceptibility starts and also the effect of the length of the period of immersion of the fruits on checking, fruits (60 in each sample) were collected at weekly intervals in two locations in 1939 and in three locations in 1940. To avoid the inclusion of fruits of widely divergent stages of development, all fruits were obtained from bunches pollinated at approximately the middle of the pollination period. In 1939 the fruits were from bunches pollinated within 7

days of March 19; in 1940, from bunches pollinated within 7 days of March 1.

In 1939 the fruits were examined after 2, 4, 24, and 48 hours of immersion. Since checking after 48 hours of immersion was about the same as that after 24 hours, immersions for 48 hours were discontinued in June. As shown in figure 3, immersion for 2 and 4 hours showed about the same relation between extent of checking and time of collection during the summer. Immersion for 24 hours caused all the fruits to check several weeks before the maximum checking was observed for the 4-hour immersion. The 4-hour period of immersion was therefore selected for determining degree of susceptibility during the summer.

In figure 4 are presented the degree-of-susceptibility curves for fruits during 1939 and 1940 from the control (plot A) of each of several series of irrigation plots in three locations. The dips in the susceptibility curves in July 1939 may have been the result of high maximum temperatures, which at the United States Date Garden ranged from 43° to 48° C. between July 8 and 14. The slightly earlier period of susceptibility to checking there than at the Cavanagh garden is probably related to the earlier fruit development and maturity at the United States Date Garden, which is the warmer location. An abnormally low set of fruit at the Cavanagh garden in 1940 resulted in a much lighter crop than at the other two locations; this lighter crop may have caused the indicated greater susceptibility of the Cavanagh fruit to checking after the 4-hour immersion in water. The dips in the curves for checking in early July 1940 coincide with a period of 13 consecutive days of maximum air temperatures of 43° or more. The time of termination of the period of susceptibility in each of the three locations corresponded to the time at which fruits attained full size and changed in color from yellowish green to pink.

The period of susceptibility to checking in relation to fresh and dry weights of the fruits is illustrated in figure 5. The 10 to 40 percent checking during June occurs at the stage in fruit enlargement when, according to Long (*7*), cell enlargement in the apical region is nearly complete. The 70 percent or more checking beginning at the end of June coincides with the period when cell enlargement in the median region is about completed. Thus the susceptibility to checking, which is confined to the apical and median regions (fig. 1), may be due to lack of elasticity of walls of cells which have ceased enlargement, or possibly to a reduction in the plasticity of the cuticle overlying the cells that have stopped growing. Maximum susceptibility to checking occurs while the fruits are approaching maximum size, growth being largely the result of enlargement of cells in the basal region (*5*, *7*).

In all five cases where weekly fruit samples were obtained, the relatively abrupt termination of the period of susceptibility to checking was associated with the change from an increase in total amount of water per fruit to a decrease in total amount of water per fruit (fig. 5, *C*). This would be expected to result in a reduction in the turgor of the fruit as a whole, which would lessen the strain on the walls of the peripheral cells and cuticle, as suggested by Haas and Bliss (*5*).

When the period of susceptibility to checking ceases, the fruit becomes susceptible to khalal cracking and to tearing. Tearing is

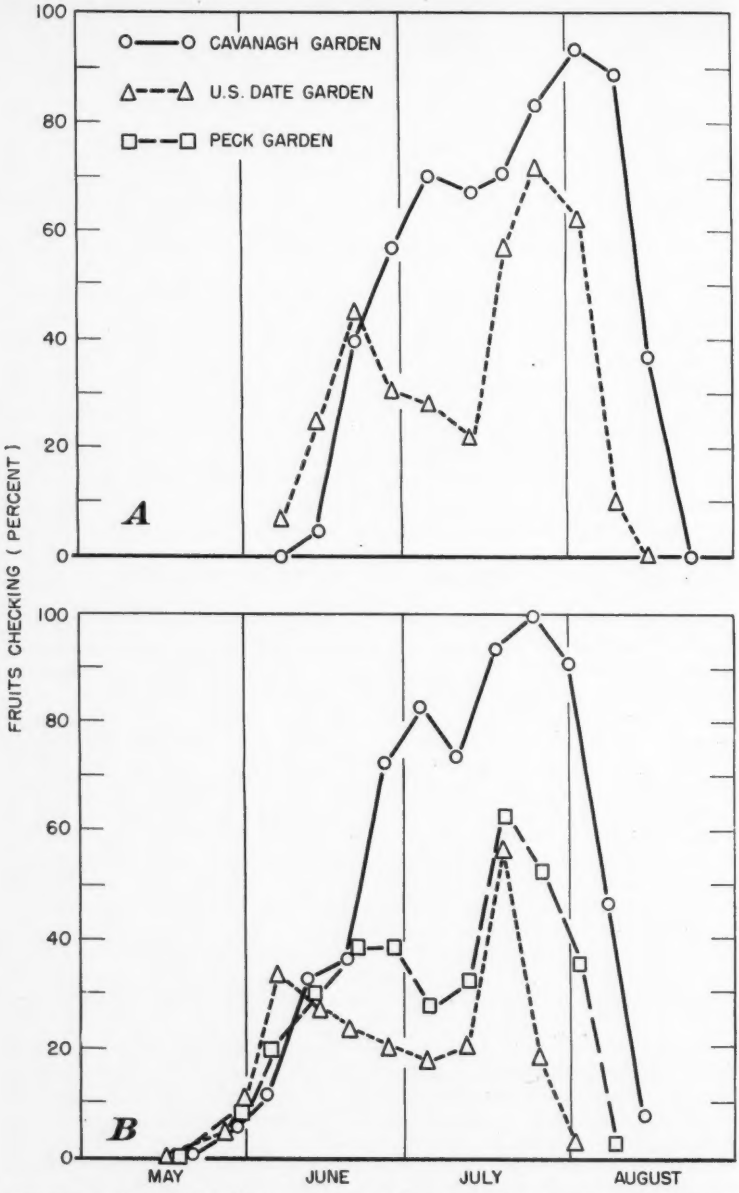

FIGURE 4.—Date fruits checking after a 4-hour immersion in water, in relation to time of collection during the summer: *A*, Cavanagh garden and United States Date Garden, 1939; *B*, Cavanagh and Peck gardens and United States Date Garden, 1940.

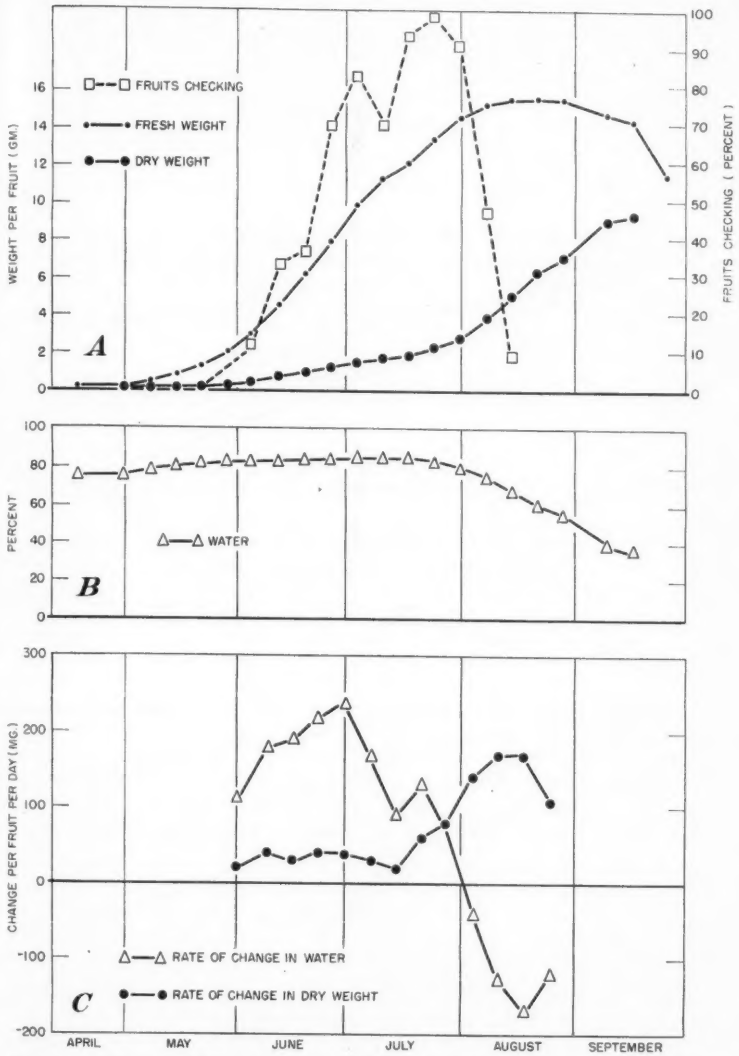

FIGURE 5.—Susceptibility of dates to checking in relation to normal development of the fruits in Cavanagh plot B, 1940: *A*, Fresh weight per fruit, dry weight per fruit, and percentage of fruits checking; *B*, percentage of water; *C*, rate of increase or decrease in water and dry weight per fruit.

the formation of a few long, deep cracks involving mesocarp as well as epidermal and hypodermal cells. In the severest form of tearing the outer mesocarp separates from the inner mesocarp and rolls back.

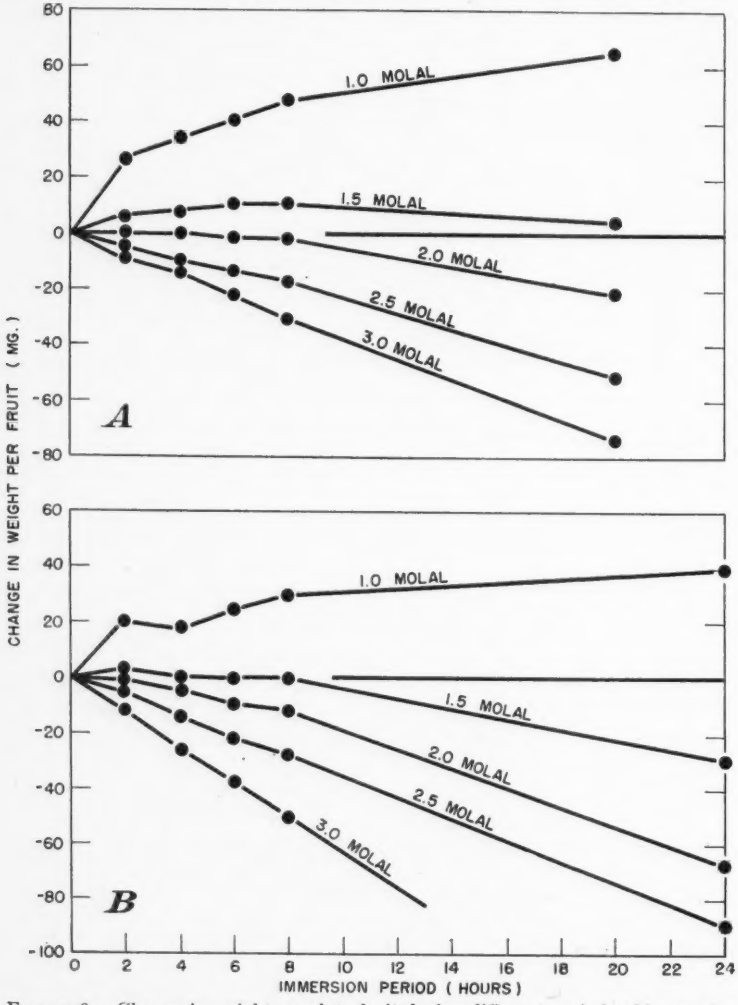

FIGURE 6.—Change in weight per date fruit during different periods of immersion in sucrose solutions of various molal concentrations: *A*, Fruits immersed at 11 a. m. on June 15; *B*, fruits immersed at 7 a. m. on June 16.

This change in manner of rupture of the fruit may be related to other developmental changes in the fruit. The rapid increase in dry weight per fruit, shown by Haas and Bliss (*5*) and by Rygg [4] to be

[4] RYGG, G. L. COMPOSITIONAL CHANGES IN THE DATE FRUIT DURING GROWTH AND RIPENING. U. S. Tech. Bul. 910. illus. 1946.

almost entirely due to sucrose accumulation, has begun. This may result in a large increase of osmotic pressure of the cell sap in the mesocarp region of the fruit, which will increase the potential turgor of the cells if their walls are no longer capable of appreciable stretching. Since at this time the inner mesocarp cells have attained their maximum length, according to Long (7), it is likely that very little stretching of cell walls can occur. The susceptibility to tearing ceases when the fruit tissue begins to soften, at which stage the cells apparently lose their semipermeability.

RELATION OF CHECKING TO WATER INTAKE OF DETACHED FRUITS IMMERSED IN WATER AND IN SUCROSE SOLUTIONS

In a preliminary estimation of the diffusion-pressure deficits in the fruits in 1938, fruits collected on June 13 were immersed in sucrose solutions of 0.5, 0.6, 0.7, 0.8, 0.9, and 1.0 molal concentrations. At the end of 2 hours fruits in all solutions had increased in weight about 0.07 gm. per fruit. On June 15 fruits were immersed at 11 a. m. and on June 16 at 7 a. m. in sucrose solutions of 1.0, 1.5, 2.0, 2.5, and 3.0 molal concentrations and then weighed at intervals for 24 hours. As shown in figure 6, fruits in 1.0 molal concentration increased in weight, while those in 2.5 and 3.0 molal concentrations decreased in weight.

On the basis of these results, lots of four fruits were collected weekly before 7:30 a. m. and immersed 4 hours in sucrose solutions of 1.1, 1.3, 1.5, 1.7, and 1.9 molal concentrations, as well as in water. The numbers of fruits developing checking are given in table 1, and the average changes in weight are shown in figure 7.

Although fruits immersed in 1.5, 1.7, and 1.9 molal sucrose solutions consistently decreased in weight, they developed checking nearly as readily as fruits which increased in weight in water. Thus checking was not necessarily accompanied by increased absorption of water by the fruit as a whole, although it probably resulted from water movement into certain cells to the extent that the increased turgor caused a rupture in the cutinous layer and in the epidermal and hypodermal cells. The relatively slight changes in weight of fruits immersed in 1.1 molal sucrose solution indicate that fruit collected in the early morning during July and August developed as a whole a diffusion-pressure deficit of about 30 atmospheres.

TABLE 1.—*Effect of concentration of sucrose solution upon number of fruits showing checking after immersion for 4 hours*

[4 fruits in each lot]

Type of solution	Fruits developing checking, for each collection date										
	July				August				September		
	7	14	21	28	4	11	18	25	8	15	22
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Water	4	4	4	4	4	4	3	2	2	(1)	(1)
1.1 molal	0	4	4	1	4	4	4	2	0	0	(1)
1.3 molal	0	3	4	3	4	3	3	0	0	0	0
1.5 molal	1	4	4	3	4	4	3	2	0	0	0
1.7 molal	3	4	4	4	4	4	3	0	0	0	0
1.9 molal	0	4	4	4	4	4	3	0	0	0	0

[1] Fruits developed tearing.

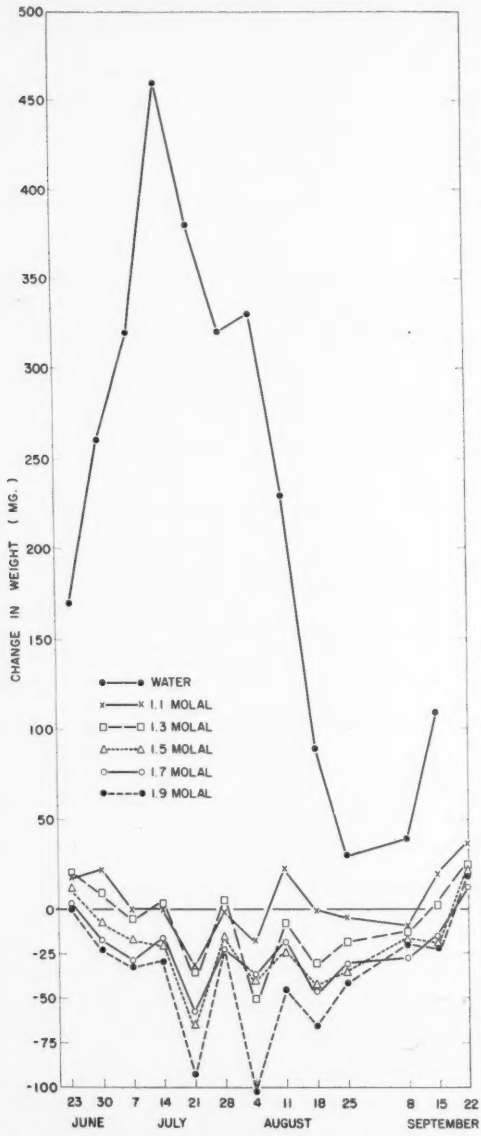

FIGURE 7.—Change in weight per date fruit after 4-hour immersion in water or in sucrose solutions of various molal concentrations.

For fruits immersed in water the trend for increasing amount of water absorption from June 23 to July 14, but decreasing amount of water absorption after July 14, is probably related to the relative proportion of the fruit in which cells were enlarging rapidly. The June 23 to July 24 period coincided with the period of most rapid fruit enlargement, during which Long (*7*) observed cell enlargement throughout the fruit. After July 4, when fruit enlargement became progressively less rapid, cell enlargement was found to be confined to the basal part of the fruit. Thus it seems likely that the hydration capacity of actively dividing or enlarging mesophyll cells is greater than that of fully enlarged cells.

Morning and afternoon collections of fruits on August 23 were immersed in water and in sucrose solutions (table 2). After immersion the fruits in the morning collection showed some checking, but those in the afternoon collection showed little or none. Since the fruits normally shrink appreciably during the day (*8*), they presumably have a lower water content in the afternoon, so that a smaller water supply within the fruits in the afternoon than in the morning may have prevented checking. This evidence is interpreted as substantiating a concept that water within the fruit moves into the peripheral cells which develop the excessive turgor that causes checking, while the effect of the solution surrounding the immersed fruit is largely to reduce the rate of diffusion of water out of the fruit and to allow accumulation of water in the peripheral region.

TABLE 2.—*Effect of time of collection upon number of fruits showing checking after immersion in water or sucrose solutions*

[4 fruits in each lot]

Immersion period and collection time	Fruits that developed checking in indicated solution					
	Water	2.0 molal	3.0 molal	4.0 molal	5.0 molal	6.0 molal
4-hour immersion:	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
7:50 to 8:15 a. m.	3	3	3	3	1	1
2:40 to 2:50 p. m.	0	0	0	0	0	0
24-hour immersion:						
7:50 to 8:15 a. m.	4	3	4	3	2	2
2:40 to 2:50 p. m.	1	1	0	1	0	0

A consideration of the probable magnitude of the vapor-pressure gradient of water from epidermal cells of the fruit to the outside air gives plausibility to this explanation of checking. If the concentration of sap in epidermal cells at zero turgor is assumed to be 2 molal, the temperature of fruit and air to be 25° C., and the relative humidity of outside air to be 50 percent, then the water-vapor-pressure gradient from the cells through the cuticle to the air might amount to about 10.89 mm. Hg (22.77 mm. for vapor pressure of cell sap minus 11.88 mm. for vapor pressure of outside air). With such a vapor-pressure gradient causing water to move from the epidermal cells to the outside air, the water vapor might be expected to move through the relatively impervious cuticle at a rate greater than that at which water might be moving from the interior of the fruit to the epidermal cells, and the cells would not develop an excessive turgor. However, when the fruit is immersed in a 3.0 molal sucrose solution, the water-vapor-pressure gradient from epidermal cells to the outside

solution might initially be about 0.59 mm. Hg (22.77 mm. minus 22.18 mm.). Then the rate of water movement from the epidermal cells to the outside solution might become slower than the rate of movement from the interior of the fruit to such cells, resulting in excessive turgor and checking of the epidermal cells.

Additional evidence that water within the fruit may cause the checking was obtained by a simple experiment. Three lots of 20 fruits each were collected in early morning, and the perianths of all fruits were sealed with melted paraffin. One lot was dipped in melted paraffin to seal the entire fruit surface and then was exposed to laboratory air; the second lot was immersed in water; and the third lot was left with the fruit surface exposed to laboratory air. At the end of 4 hours all fruits completely covered with paraffin were checked as much as the fruits immersed in water, but the fruits with their normal surface exposed to air showed no checking. Thus, preventing water movement out of the turgid fruits without allowing water movement into the fruits resulted in checking.

EFFECT UPON CHECKING OF VARYING THE WATER SUPPLY TO DETACHED STRANDS OF FRUIT

To investigate further the relation to checking of water supplied to the fruits through the vascular system and of water vapor in the air surrounding the fruits, the basal end of a detached strand of fruit was connected to a water supply from a burette while another detached strand was left without this supply of water. The two strands were then suspended with the fruits of both enclosed in the same chamber for 6 to 8 hours. Two such chambers were used in each of two experiments. In the first experiment the air in chamber 1 was maintained at about 76 percent relative humidity by passing into it air which had bubbled through a series of saturated solutions of sodium chloride; the air in chamber 2 was maintained at 100 percent relative humidity by warm water in the bottom of the chamber. The second experiment was similar, except that in chamber 1 the air was maintained at about 95 percent relative humidity by passing the air through a series of saturated solutions of $Na_2HPO_4.12H_2O$. The air temperatures were about 25° C. The percentages of fruits developing checking are given in table 3.

TABLE 3.—*Effects of water supply to a strand of detached fruit and of relative humidity of the surrounding air upon the percentage of checking, 1938*

Date and relative humidity of air surrounding fruits	Strand with or without water supply	Fruits per strand	Fruits checking
July 17:		*Number*	*Percent*
76 percent	With	10	60
Do	Without	9	0
100 percent	With	24	100
Do	Without	24	46
July 18:			
95 percent	With	10	100
Do	Without	11	0
100 percent	With	23	100
Do	Without	24	21

The fact that where water was supplied to the strand checking occurred while the fruits were in air at 76 percent relative humidity indicates that the excessive turgor of the peripheral cells can develop

with the vapor pressure of the water in the air surrounding the fruits less than the lowest possible vapor pressure of water in the cell sap, provided the supply of water from the strand to the fruits is relatively great. The greater checking shown by fruits on strands supplied with water than by those on strands not supplied with water, with the same relative humidity of the surrounding air, shows that the availability of water to the fruits from the strand is an important factor in causing checking.

EFFECT UPON CHECKING OF VAPOR-PRESSURE DEFICIT OF AIR SURROUNDING FRUITS ON THE PALM

Although all fruits on detached strands supplied with water developed checking when exposed to air at 95 percent relative humidity,

FIGURE 8.—Apparatus for passing air of approximately constant water-vapor-pressure deficit over date fruits on the palm.

additional work was necessary to determine whether fruits on the palm would be equally susceptible to checking. This determination necessitated a technique that would maintain approximately constant relative humidity of air under field conditions, despite the water from fruit transpiration and the fluctuations in outside air temperatures. The apparatus used is shown in figure 8.

Air was forced by a pump capable of moving 4.3 cubic feet of air per minute against a pressure of 10 pounds through two parallel lines. In one line the air was saturated with water by bubbling it through warm water; in the other line the air was dried by passing it through sulfuric acid. These two air streams were then mixed, and by regulating the relative volumes of air through the two lines the water-vapor

content of the ultimate mixture was adjusted. This final air stream was passed into a chamber enclosing one strand of fruit and was allowed to escape through a tube in the cover. As the escaping air stream had a velocity exceeding 10 feet per second, a wet-bulb thermometer suspended in this escaping air stream gave reliable values. Since the pressure drop from the inside of the chamber to the outer end of the tube in the cover was very small, the water-vapor-pressure deficit of the escaping air stream was probably within ±0.2 mm. Hg of that of the air around the fruits. Fruit temperatures were assumed to approximate closely those of the dry-bulb thermometer in the air stream. In spite of frequent adjustments of the wet- and dry-air streams, sudden changes of 2° to 3° C. in outside air temperature occasionally caused temporary fluctuations of 1 to 1.5 mm. in vapor-pressure deficit of the air surrounding the fruits. Generally, however, wet- and dry-bulb thermometer readings were kept within ±0.3° of the desired temperature difference so that vapor-pressure deficit of the air stream was maintained within about ±0.6 mm. Hg of the desired value. No checking developed on control fruits outside of the apparatus during any of the runs. The percentages of fruits that developed checking in the controlled air stream are given in table 4.

TABLE 4.—*Effect upon the percentage of fruits checking of water-vapor-pressure deficit of air around fruits on the palm*

Run No.	Date	Clock time	Approximate vapor-pressure deficit	Approximate relative humidity	Fruits exposed	Fruits checking
	1939		*Mm. Hg*	*Percent*	*Number*	*Percent*
1–A	July 27–28	7 p. m.–10 p. m	1.4	96–95	22	32
1–B		3 a. m.–6 a. m	1.4	95–94	42	40
2–A	Aug. 1–2	3 p. m.–6 p. m	1.4	96–95	55	0
2–B		7 p. m.–10 p. m	1.4	96–95	53	0
2–C		3 a. m.–6 a. m	1.4	95–94	59	0
2–D [1]		7 a. m.–9 a. m	1.4	95–94	25	100
3–A	Aug. 2–3	10 p. m.–10 a. m	1.4	96–94	28	32
3–B [1]		7 a. m.–10 a. m	1.4	95–94	25	88
4–A	Aug. 3–4	7 a. m.–10 a. m	2.8	92–91	29	24
4–B [1]		4 a. m.–10 a. m	2.8	92–91	55	42
5–A	Aug. 8–9	6 p. m.–6 a. m	2.8	92–91	19	0
5–B		12 p. m.–6 a. m	2.8	92–91	26	0
6–A	Aug. 9–10	6 p. m.–6 a. m	1.2	96–95	24	0
6–B		12 p. m.–6 a. m	1.2	96–95	27	0
7–A	Aug. 10–11	6 p. m.–6 a. m	.6	98	28	36
7–B		12 p. m.–6 a. m	.6	98	28	18
	1940					
8–A	July 12–13	6 p. m.–6 a. m	1.0	97–96	50	84
8–B [2]					10	90
9–A	July 15–16	do	0.5–1.0	98–96	54	96
9–B [2]					10	100
10–A	July 16–17	do	3.0	91–90	53	52
10–B [2]					11	100
11–A	July 23–24	do	3.0	91–90	54	93
11–B [2]					9	100

[1] Strand severed from bunch, but fruits were inside the chamber as in other runs. The cut end of the strand was supplied with water under a small force.
[2] Strand left attached to palm, but fruits were inserted in a thermos jug in still air.

The exposure of fruit on the palm to air with a relative humidity of 91 to 96 percent did not cause any checking during some nights, but during others it resulted in the checking of as many as 93 percent of the fruits. However, when the strands were severed and supplied

with water (runs 2 to 4), the checking of fruits was greater on these severed strands than on those still connected to the palm. This indicates that the water-vapor-pressure deficit of the air was low enough and the period of exposure long enough to cause checking, but the water supply from the palm to the fruit was not adequate. However, when weather conditions with high relative humidity cause checking of fruits, the rate of water movement out of the leaves as well as out of the fruits is reduced to the extent that the turgor of the palm as a whole is increased sufficiently to increase the supply of water from the palm to the fruits. Since the effects of weather conditions upon the turgor of the palm may have persisted for several days, it was not possible from the weather records available to relate the results in this experiment to weather except in the most general terms. Apparently cloudiness and a maximum air temperature under 40° C. during the day preceding the night of the run favored the development of checking, whereas clear skies and temperatures of 42° or more during the day preceding the run were unfavorable for checking.

When fruits on a strand attached to the palm were enclosed during the night in a thermos jug (runs 8 to 11), by morning droplets of water were scattered over the inner surface of the jug and over the surface of the fruits, apparently as a result of transpiration and a decrease in temperature of the air within the jug. The fact that there was more checking of fruits in the jug than of those in the air stream showed that for the same water supply from the palm to the fruits a reduction in water-vapor-pressure deficit of the air surrounding the fruits from about 1 mm. Hg to approximately 0 increased the percentage of fruits developing checking. Thus, these results tend to confirm the hypothesis that any condition that favors increase in turgor of the cells of the peripheral region, either by reducing water loss from the fruits or by increasing translocation of water into the fruits, favors checking.

RATE OF TRANSPIRATION BY FRUITS ON THE PALM

The evidence indicating that checking tended to be increased by a relatively slow rate of water loss from the fruits prompted an attempt to measure the rate of transpiration by fruits on the palm. In 1939 this was estimated by determining the difference in moisture content between a stream of outside air after it had passed over two or more strands of fruits (60 to 70 fruits) in a shaded glass chamber and a similar stream before it passed over them. The air stream of 283 to 340 liters per hour was sufficiently rapid to prevent large changes in temperature or relative humidity of the air while in contact with the fruits. The resistance to flow through the large-diameter, short inlet tube caused very little reduction of pressure in the chamber below that of the outside air.

Each air stream was drawn through flexible copper tubing to a train consisting of (1) two gas washing bottles of concentrated sulfuric acid (in which the water vapor was absorbed and weighed), (2) a flowmeter (used as indicator of the rate of flow), (3) two gas washing bottles of water (to saturate air with water vapor), and (4) a wet gas meter (to measure the total volume of air passing through the train). Pressures in the wet test meters were held practically constant by

slight adjustments of needle valves between the meters and the vacuum pump. Temperatures and pressures in the meters were read at intervals and averaged for a run. The observed volumes of air were corrected to standard conditions, and the average loss of water per fruit per hour was calculated for each run.

The average transpiration rate of fruits on one palm in each of the irrigation plots A (control) and BC (appreciable water deficits in the palm from June 16 to August 17) at the United States Date Garden was determined several times during the summer for 24-hour periods, divided into six runs of about 4 hours each. The average transpiration per fruit per hour is shown in figure 9. The observed transpiration rates of the fruits in plot BC were considerably lower than those in plot A until after August 17. This indicates that while there were appreciable water deficits in the palm in plot BC, the rate of transpiration of the fruit was reduced by a limitation in the supply of water from the palm to the fruits. During the daytime in July and August the indicated average rate of transpiration was about 40 mg. of water per fruit per hour and was never found to exceed 60 mg. These values are only slightly higher than those estimated by Haas and Bliss (*5*), based upon repeated weighings of detached, nearly ripe fruits on September 13, 1933.

The highest rate of transpiration in the 24-hour period was, as might be expected, usually during the 4-hour period at midday or during the early afternoon. From this maximum, transpiration decreased during the afternoon and night to a minimum during the early morning, at which time air temperature and vapor-pressure deficit were also at a minimum. After the relatively humid night of August 2–3, when the average rate of transpiration became as low as 6 mg. per fruit per hour, several large fruits on heavily thinned bunches were observed to develop fresh checks at sunrise.

The capacity of transpiration by the fruits to increase the water vapor in the air surrounding them may be one of the factors that cause the checking. A bunch of 1,000 fruits, each transpiring at the rate of only 10 mg. per fruit per hour, could saturate 100 liters of still, dry air (at 25° C.) in 18 minutes. This emphasizes the importance of the results of Haas and Bliss (*5*) showing that conditions which reduce the circulation of the air in the fruit bunch increase checking. However, when weather conditions reduce the vapor-pressure deficit of the air, transpiration by the leaves as well as by the fruits is retarded. As pointed out earlier, a retardation of transpiration by the leaves would be expected to favor checking of fruits by increasing the supply of water from the palm to the fruit.

REDUCTION OF CHECKING OF FRUITS ON THE PALM IN RELATION TO APPRECIABLE WATER DEFICITS IN THE PALM

The evidence thus far points to water deficits in the fruit resulting either from a greater rate of water movement out through the fruit surface than into the fruit from other parts of the palm or from withdrawal of water from fruit by transpiring leaves as factors reducing fruit susceptibility to checking. Since appreciable water deficit in the palm resulting from soil-moisture deficiency should materially reduce water movement from palm to fruit and thereby increase water deficit in the fruit, such water deficit in the palm should reduce

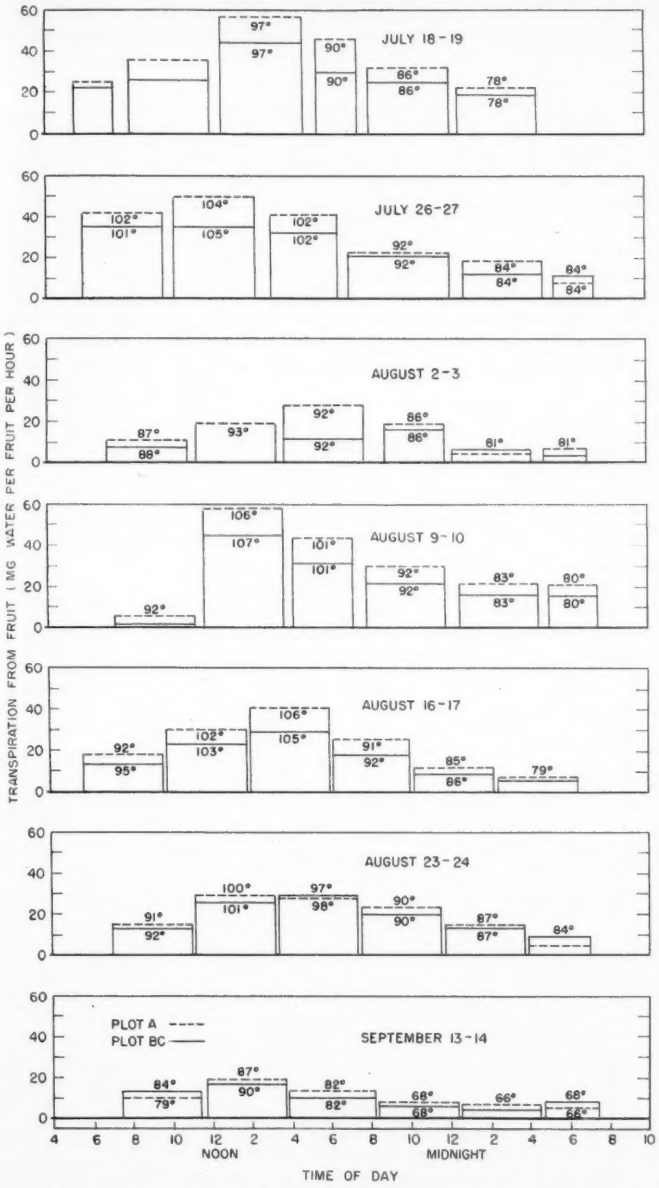

FIGURE 9.—Average rate of transpiration of date fruit for 4-hour periods in seven runs, for one strand of fruit in irrigation plot A and plot BC, respectively, at the United States Date Garden, 1939. The average temperature (° F.) of the air surrounding the fruit in each chamber is indicated for each run.

checking. Several series of irrigation plots, described elsewhere (*1*, *8*), provided an opportunity to relate the percentage of fruits developing checking or blacknose to appreciable water deficit in the palm resulting from soil-moisture deficiency. With the omission of irrigations in a certain plot, appreciable water deficits in the palms in that plot were indicated when the rate of leaf elongation became 0.5 cm. or more per day lower than that of regularly irrigated palms (representing the commercial practice or "control"). After the resumption of irrigation of palms that had been showing appreciable water deficits, the rate of leaf elongation did not immediately increase to that of the control palms; but for this discussion the period of appreciable water deficits will be considered as terminated when the period of soil-moisture deficiency ended. The average percentages of fruits in each plot showing checking or blacknose (table 5) were based upon counts of fruits on two inside and two outside strands on each of three bunches per palm pollinated at the peak of inflorescence emergence.

TABLE 5.—*Effects of appreciable water deficit in palms, as measured by reduced rate of leaf elongation below that in control plot, upon percentage of fruits showing checking or blacknose*

Year and location	Grower's practice or control [1]			Plots showing appreciable water deficit during indicated periods [1]			
	Plot	Fruits showing—		Plot	Period of water deficit	Fruits showing—	
		Checking	Blacknose			Checking	Blacknose
1938:		*Percent*	*Percent*			*Percent*	*Percent*
Martinez Indian Reservation	C	.....	16	A	July 10–Aug. 7	.....	1
				B	July 30–Sept. 8	.....	2
1939:							
United States Date Garden	A	38	0	BC	July 16–Aug. 17	9	0
Cavanagh garden	A	33	3	B	June 18–July 18	20	1
				C	July 4–Aug. 4	22	1
				D	Aug. 3–Aug. 30	31	3
1940:							
Cavanagh garden	A	69	30	B	June 13–July 4	34	2
				C	July 10–Aug. 7	1	0
				D	Aug. 20–Sept. 17	55	15
Peck garden	A	39	12	C	July 10–Aug. 4	6	1
Martinez Indian Reservation	A–1	15	10	C–1	July 1–Aug. 6	2	1
	A–2	12	3	C–2	July 1–Aug. 6	0	0
	A–3	9	3	C–3	July 1–Aug. 6	0	0

[1] Plot designations are those used in other publications (*1*, *8*) referring to these irrigation plots.

From table 5 it is evident that in all 10 plots where omission of irrigation caused appreciable water deficits in the palm at any time from the middle of June to the early part of August the percentage of fruits that developed checking was smaller than in comparable control plots. That period has already been shown (fig. 4) to correspond in 1939 and 1940 to the developmental stages of the fruit when it is susceptible to checking. In the location used in 1938 the fruit remained susceptible to checking until after August 18. Therefore it is not surprising that the appreciable water deficits from July 30 to September 8, 1938, also reduced the percentage of blacknose. On the other hand, at the Cavanagh garden in 1939 and 1940 the periods of water deficits that started in August, just before the termination of

the period of susceptibility to checking, appeared to have little or no effect upon the percentage of fruits developing checking.

DISCUSSION

Frazier (*4*) and Brown and Price (*2*) found in the relatively humid Eastern States that irrigation increased the cracking of tomato fruits. Presumably the unirrigated plants developed appreciab e water deficits during periods without rain. Werner and Dutt (*14*) reduced cracking of Triumph potato tubers by root cutting, which apparently reduced water supply from plant to tuber.

The data do not show any indication that irrigation following a retardation in fruit growth during the period of normal fruit susceptibility to checking increased the tendency to checking, as observed by Frazier (*4*) in the cracking of tomatoes. On the contrary, appreciable water deficits during the first half of the period of normal fruit susceptibility to checking in the date (plot B at Cavanagh garden in 1939 and 1940), followed by regular irrigation during the latter half of the susceptibility period, resulted in a smaller percentage of fruits checking than in the control. Weekly sampling of fruits showed that the water deficit in plot B, as compared with plot A (control), reduced the size of the fruit and the rate of dry-matter accumulation in the fruit during late August or during September (*1*). Consequently, the water deficit in the palm in late June and early July may have had some persisting effect upon the fruit which caused it to be less susceptible to checking after the regular 10-day irrigations had been resumed.

The data showing less checking in detached strands of fruits without water than in those supplied with water suggest that the appreciable water deficits in the palm resulting from soil-moisture deficiency prevent checking by reducing the rate of water movement from the palm to the fruits. The association of reduced checking with the slightly lower rate of transpiration in the comparison of plot BC with plot A (table 5 and fig. 9) is supporting evidence. Other evidence, however, indicates that one or more factors other than reduced rate of water movement to the fruits are also operative. Appreciable water deficits in the palm as a result of soil-moisture deficiency prior to the middle of July were effective in reducing checking several weeks later, when a resumption of irrigation had presumably provided a normal supply of water from the palm to the fruits. Since these water deficits also reduced the size of the fruits and retarded the rate of dry-matter accumulation in the fruits during the late summer (*1*), it might be supposed that the water deficits effective in reducing checking had a profound influence upon the physical and chemical condition of the critical peripheral cells.

Long (*7*) observed that cell enlargement in the median regions of the date fruit continued into July. Therefore, in the case of appreciable water deficit before the middle of July, the cells in the distal part of the fruits may have remained smaller than those of fruits on palms without such water deficit. With their reduced wall surface, such smaller cells would, if wall thickness were not affected, be expected to resist greater turgor pressures than larger cells.

Since the period of fruit susceptibility to checking coincides with the latter part of the period of fruit enlargement, the tendency of the walls of the epidermal and hypodermal cells to rupture may be

directly related to a strain on the walls while final fruit enlargement occurs, as Verner (*12*, *13*) suggested in the case of Stayman Winesap apples. The extension of peripheral cells during the longitudinal growth of the date fruit, which has been observed by Long (*7*), is shown in figure 2. By reducing the growth of cells causing fruit enlargement, appreciable water deficits may reduce the forces which, by stretching the walls of the critical epidermal and hypodermal cells, make the cells more subject to rupture during abnormally high turgor. That susceptibility to checking is closely related to factors affecting date-fruit growth has already been pointed out by Nixon and Crawford (*10*, *11*), who found that fruit thinning that increased fruit size also increased checking and blacknose.

SUMMARY

To learn more of the role of water in the checking (a type of cracking) of date fruits, the amount of checking of both detached fruits and fruits on the palm was studied in relation to the internal water supply of the fruit and to the water in the medium surrounding the fruit.

Fruits detached from the palm in the morning developed checking after immersion in water for 4 hours. Repetition of this test at weekly intervals during the summer showed that the period of fruit susceptibility to checking began in June and ended in August when the fruit color had changed from yellowish green to pink. The relatively abrupt termination of the period of susceptibility to checking coincided with the developmental stage at which the total weight of water per fruit stopped increasing and began to decrease. When fruits detached in the morning were immersed in 1.5, 1.7, and 1.9 molal sucrose solutions, the fruits decreased in weight but developed checking nearly as readily as fruits immersed in water. The suggested explanation is that during immersion the rate of water movement from the peripheral cells through the cuticle to the sucrose solution was slower than the rate of water movement from the interior of the fruit to these peripheral cells, resulting in excessive turgor and rupture of the cells. Fruits collected in the morning and covered with paraffin checked as much in air as comparable fruits immersed in water, showing definitely that checking can occur without the entrance of water through the surface of the fruit.

When fruits on detached strands were exposed to air at relative humidities of 76, 95, and 100 percent, respectively, the checking was greater if water was supplied to the cut end of the strand. This indicated the importance of water movement to the fruit through its vascular system as a cause of checking. When the exposure of fruits on the palm to air of a relative humidity of 91 to 96 percent did not result in as much checking as when the strand was severed and supplied with water, the checking of the fruit on the palm was apparently being limited by insufficient translocation of water from the palm to the fruit.

The rate of transpiration of fruit during July and August was found to vary from a maximum of 30 to 60 mg. of water per fruit per hour at midday or early afternoon to a minimum of 5 to 20 mg. in the early morning. A generally lower rate of transpiration by fruit on a palm with soil-moisture deficiency than by fruit on a palm with adequate soil moisture indicated that with appreciable water deficits in the

palm the rate of movement of water from the palm to the fruit was reduced.

In a series of irrigation plots, an increased water deficit in the palm as a result of soil-moisture deficiency, in comparison with slight water deficits in adequately irrigated palms, invariably reduced the percentage of fruits that developed checking, provided the increase in water deficit occurred during the period of fruit susceptibility to checking. This reduction in susceptibility of fruit to checking caused by appreciable water deficits may have resulted from a reduction in the supply of water from the palm to the fruit, a reduction in the size of cells, or a reduction in the amount of stretching of the walls of peripheral cells.

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